AD-A118 896 NAVAL RESEARCH LAB WASHINGTON DC F/G 17/1
STERN-ASPECT NOISE RADIATED BY THE CYCLOIDALLY PROPELLED VESSEL--ETC(U)
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Cycloidally Propelled [illegible]
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Conventionally Propelled Vessels

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Large Aperture Acoustics Branch
Acoustics Division

August 27, 1982

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 8623	2. GOVT ACCESSION NO. AD-A118 896	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STERN-ASPECT NOISE RADIATED BY THE CYCLOIDALLY PROPELLED VESSEL *SEACON* AND ITS COMPARISON WITH THAT RADIATED BY CONVENTIONALLY PROPELLED VESSELS		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. C. Wales and B. B. Adams		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, DC 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62759N XF59552100 51-0371-0-2
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronic Systems Command Washington, DC 20360		12. REPORT DATE August 27, 1982 13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stern-aspect radiated noise
Tow-ship noise
Cycloidal propellers
Voith-Schneider propellers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The stern-aspect radiated noise of the cycloidal-propeller-powered vessel *Seacon* (Naval Facilities Engineering Command) was measured and compared with that of several conventionally powered array tow-ships used by the Navy. The radiated noise spectra of the *Seacon* ranged from 150 to 130 dB re 1 μPa/m − Hz over the frequency range 100 to 500 Hz for low-thrust conditions and 153 to 133 dB μPa/m − Hz over the same frequency range at full thrust (5.6 knots). The low-thrust conditions were characterized by a more pronounced line structure. For the high-thrust conditions the cavitation-noise background masked most of the lines. Above 150 Hz these levels are equivalent to those of other

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20. Abstract (Continued)
vessels for which no special quieting efforts have been made. Below 150 Hz the noise spectra of the *Seacon* continued to increase at about 6 dB per octave, whereas that of the other vessels typically remained constant or peaked and declined. This continued rise is attributed to the *Seacon's* cycloidal propulsion system. Vessels for which special quieting efforts had been made were 10 to 20 dB quieter. Because of its special maneuvering capabilities the *Seacon* and vessels like it should be considered first when choosing platforms where station-keeping ability and slow-speed maneuvering are important. The propulsion system of the M/V *Acadian Navigator* was apparently the most effective in reducing noise, and this type of vessel is recommended for array towing.

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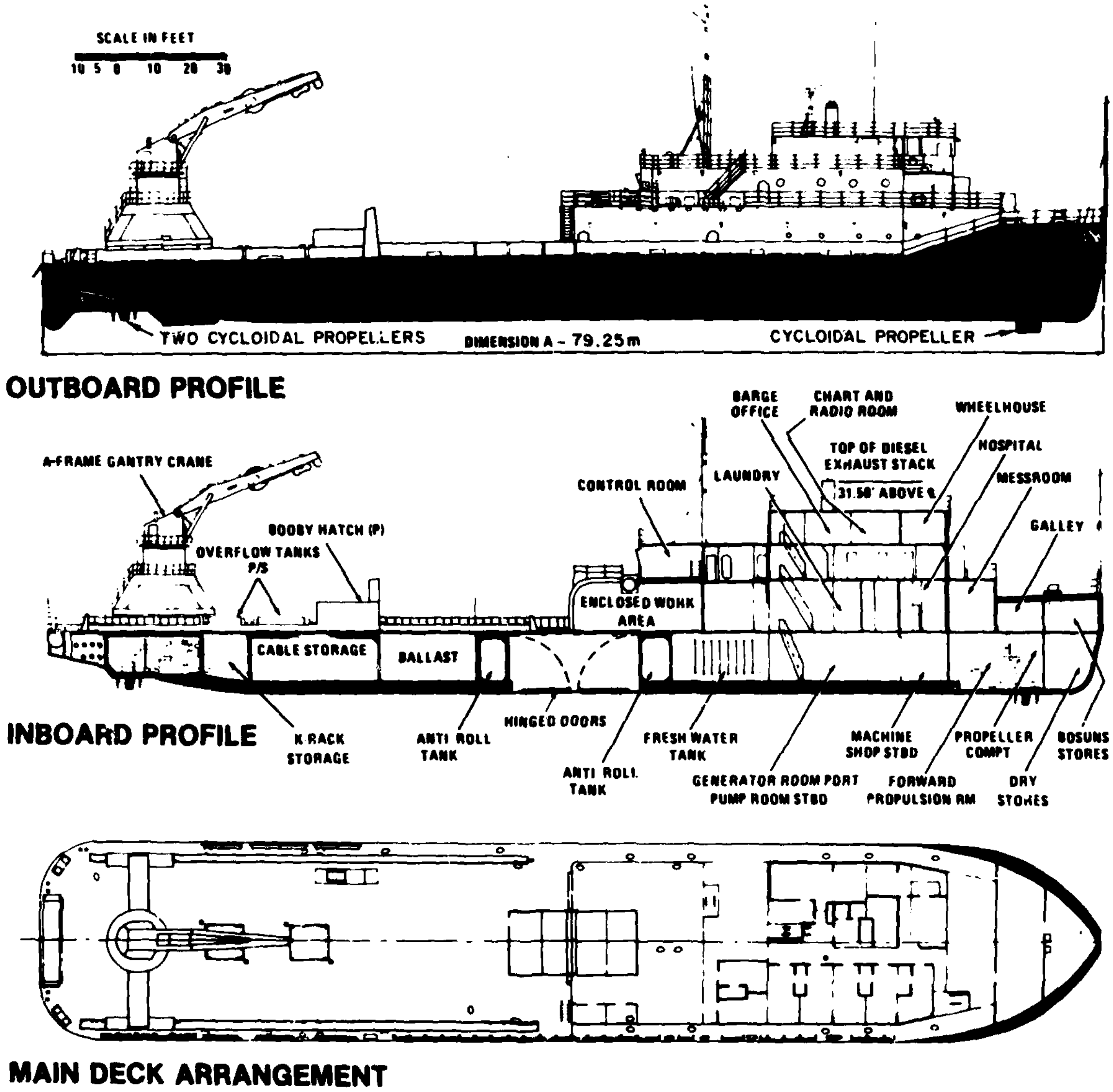


Fig. 1 — Profiles and deck arrangements of the *Seacon*. This figure was provided by the Naval Facilities Engineering Command, Chesapeake Division, Washington Navy Yard.

STERN-ASPECT NOISE RADIATED BY THE CYCLOIDALLY PROPELLED VESSEL *SEACON* AND ITS COMPARISON WITH THAT RADIATED BY CONVENTIONALLY PROPELLED VESSELS

INTRODUCTION

Of continuing interest to the Navy is the noise radiated from operating platforms or ships. This noise is the major interfering factor in the operational and research effectiveness of receiving systems over the wide frequency range of 30 to 300 Hz. We will present the results of source level measurements of the *Seacon*, a unique sea-construction vessel of the Naval Facilities Engineering Command, which is also an especially attractive engineering-development platform for large-scale acoustic arrays. This vessel employs three Voith-Schneider cycloidal propellers which provide superior maneuvering and station-keeping abilities. Previously reported noise measurements of vessels using this type of propulsion system has been confined to kilohertz frequencies [1,2]. Thus, although the primary purpose of our measurements was to assess the *Seacon* as a possible development-and-test platform by comparing its noise levels with those of other candidate vessels, our measurements are of some interest by themselves because of this unique propulsion system, which is also installed on a class of research vessels exemplified by the R/V *Melville* of the Scripps Institution of Oceanography and the R/V *Knorr* of the Woods Hole Oceanographic Institution.

THE *SEACON*

The *Seacon* (Fig. 1 and Table 1) was rebuilt in 1976 using the hull of a barge (YFNB-33) formerly operated by NASA to carry Saturn-5 components to Cape Canaveral. The vessel is equipped with three Voith-Schneider cycloidal propellers: two aft and one near the bow. The four blades of each propeller point straight downward and revolve about a common vertical axis. Propulsion is provided by changing the angle of attack on each blade as it reaches different positions in each revolution. The propulsion system provides excellent maneuvering capabilities, but with the installed

Table 1 — Physical Description of the *Seacon*

Length	79 m
Beam	15 m
Displacement/draft	
Light	919 metric tons/1.2 m
Full load	2700 metric tons/2.4 m
Open deck space	40 by 15 m
Covered deck space	9 by 12 m
Centerwell	5 by 10 m
Towing speed	10 knots
Maneuvering speed	6 knots

Manuscript submitted June 2, 1982.

power can provide a nominal forward speed for the *Seacon* of only 6 knots; therefore the *Seacon* is normally towed to its operating sites. The power limitation does not detract from the generality of our measurements, inasmuch as virtually all acoustic-related installation-and-development work is handled within the station-keeping envelope for which this vessel was designed and is comparable to the use of other *Knorr*-class vessels.

PROCEDURE OF MEASURING NOISE LEVELS AFT OF THE *SEACON*

Because of the specialized interest in the noise level aft of the *Seacon*, the most likely location of an acoustic array being tested, our measurement procedure was straightforward: we deployed sonobuoys over the sterm of the *Seacon* while the *Seacon* moved at constant speed. Our measurements were at four speeds, corresponding to 10, 40, 70 and 100% propeller thrusts. We recorded the signal from a sonobuoy until either the sonobuoy was out of range or the noise signature from the *Seacon* had dropped to a low level.

We determined the range from the sonobuoy to the *Seacon* by using a miniranging system. The two miniranger sources were in Sand Bridge and Dam Neck, Virginia. (Fig. 2) The tracks determined using this positioning system are also shown in Fig. 2. We devised the runs to be nearly radial to one of the receivers. The maximum total range error over 4 km was a negligible 20 m, providing a highly accurate record of the separation between the source and the receiver during each individual run.

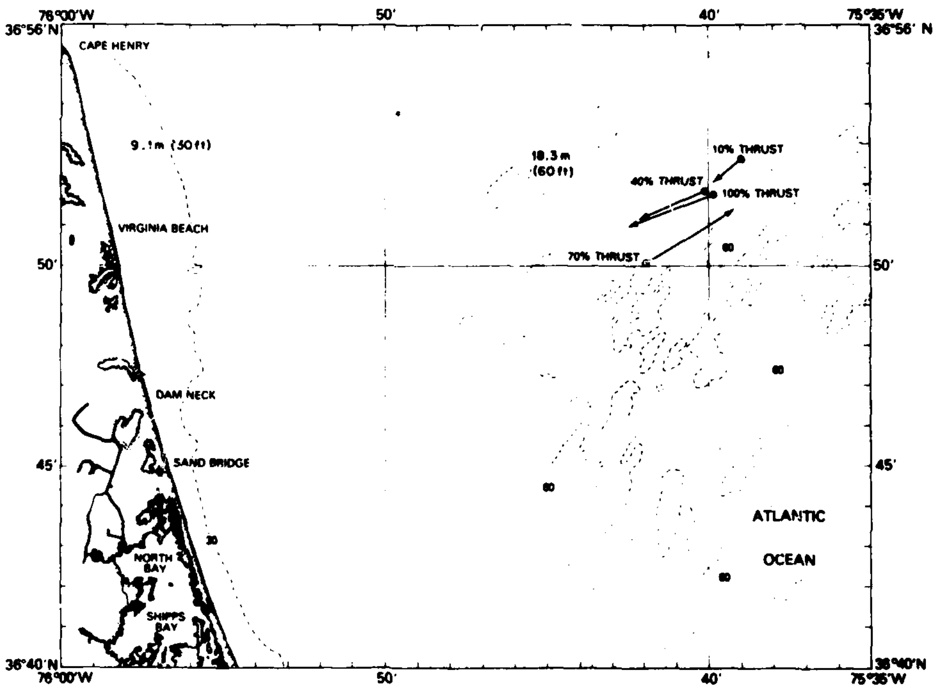


Fig. 2 — Locale where the noise levels of the *Seacon*'s propulsion system were measured. Tracks for each thrust level are indicated by the arrows

The measurement apparatus is shown in the left half of Fig. 3. The sonobuoys we used were calibrated AN/SSQ-57As set to an attenuation of −20 dB and a hydrophone depth of 18 m. We obtained calibration data for each sonobuoy from the Naval Intelligence Support Center at Suitland, Maryland. The signals were received on a standard receiver and were then FM-recorded on an instrumentation recorder at 9.5 mm/s (3-3/4 ips). Time code from a Systron-Donner time-code generator was recorded on a direct channel, and a narrowband filtered 1000-Hz calibration tone was recorded on another direct channel.

We calibrated the receiver and tape recorder by using a small test transmitter which emitted an FM signal duplicating a sonobuoy's signal. When the test transmitter produced the standard sonobuoy calibration level of 19 kHz deviation, as measured on a deviation meter, the system gain could be easily determined by measuring the output levels at the playback amplifier output of the tape recorder. An extensive calibration of this system determined that there was approximately 60 dB of total system dynamic range from recorder output levels of +10 dB re 1 v (dBv) to −50 dBv. Tape noise was generally less than −65 dBv but did rise slowly below 200 Hz, reaching −55 dBv at 50 Hz. Tape noise became significant relative to the recorded signals at 30 to 35 Hz for the lower thrust runs and at 15 to 20 Hz for the higher thrust runs, a region well below the expected band of interest in the engineering-research applications.

We played back the recorded signals on the apparatus shown in the right half of Fig. 3. The recorded levels were measured by a spectrum analyzer, with these measurements being by an xy plotter. Eight range intervals were analyzed from each run, distributed uniformly from near zero to the maximum observable range. We chose averaging times that correspond to the *Seacon* traveling about 50 m.

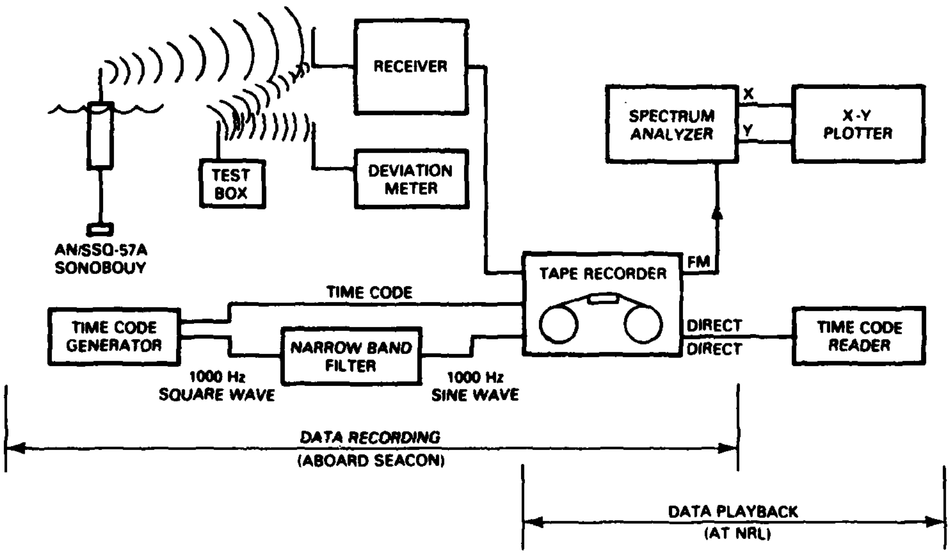


Fig. 3 — Experimental setup for the measurements of the noise radiated by the *Seacon*

COMPUTATION OF TRANSMISSION LOSSES AND SOURCE LEVELS

We will discuss the calculation of the transmission loss in detail and present evidence for our degree of confidence in the results, because the transmission loss is the principal cause of uncertainty in the calculated source levels. In analyzing the recorded data with use of a calibrated spectrum analyzer, compared its output with predictions using a version of the Fast Field Program (FFP) [3] to compute the transmission loss. The bottom was hard sand, as is indicated on the detailed Coast Guard maps for the area. For computation, we modeled the water column as 21 m deep (68.9 ft) with the source at 18.3 m (60 ft), the sonobuoy hydrophone depth, and the receiver 2 m (6.6 ft), the approximate depth of the *Seacon*'s propellers and hull. We took the sound speed in the water from archival data as 1510 M/s, and we estimated the sound speed and attenuation in the bottom from archival data [4]. The modeled bottom consisted of nine 50-m fluid layers overlying an infinite half space. We chose this bottom to most nearly represent the continuous variation with depth of the bottom properties, sound speed, and density and still remain within the computational abilities of the FFP model. Calculations of the reflection coefficients for an elastic sand layer and an equivalent fluid layer indicated differences of less than 3%. Further, calculations at 50 Hz using an elastic-layer model closely agreed with those of the fluid-layer model. Since the FFP program had trouble at the higher frequencies with the elastic-layer model, we used the fluid-layer-model results in the analysis. We calculated the transmission loss out to a maximum range of 8 km. A typical result, here for 300 Hz, is shown in Fig. 4 along with curves representing spherical and cylindrical spreading losses. We smoothed the calculations over 50-m intervals to correspond with the averaging interval in the collected data. A point represents a measured average transmission loss over the interval at the indicated range. These values represent the mean source level at each frequency and thrust minus the received level at the indicated range. The points show no significant departures from the computed trends, indicating that the calculated transmission loss has the correct range dependence, thus providing some confidence in the source-level calculations.

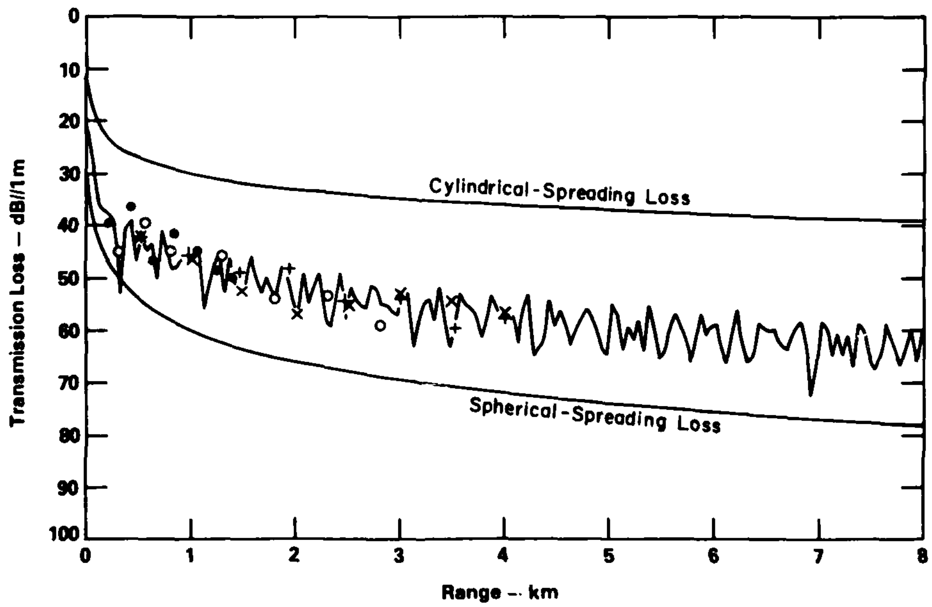


Fig. 4 — Transmission-loss curve at 300 Hz calculated by the Fast Field Program compared to the implied transmission-loss levels (symbols) for different thrust levels. Only relative transmission-loss levels are significant for the data.

We determined the source level at each range by adding to the measured level the appropriate calibration factor and the transmission loss. We obtained the transmission loss by power averaging the nearest three computed transmission-loss values; thus the transmission loss we used was the average loss over 150 m. We selected this scale as appropriate for the following reasons: the *Seacon* is almost 80 m long and to some extent may be expected to appear as a distributed source, the data-averaging time permitted the *Seacon* to move approximately 50 m, and there is some error in range due to sonobuoy-sensitivity, sonobuoy-drift, and miniranger error.

Table 2 lists the measured source levels of the *Seacon* at the different frequencies and thrusts. Source levels that are affected, to varying degrees, by spectral lines are noted. Also, the computed speeds and maximum ranges to which observations were made are included in the headings. The standard deviations indicate only the measured spread of the data. The principal causes of systematic errors are uncertainty about the sonobuoy sensitivities and error in the transmission-loss computations. The sonobuoy sensitivities are specified to be within ±2 dB; a standard deviation would be less, the errors would vary according to the run. The error in transmission-loss is harder to estimate but is probably on the same scale; errors would vary with frequency. We thus estimate the levels to be accurate to within ±3 dB for those levels whose measured spread is about ±1 dB and within ±4 dB for those with the largest spread.

Table 2 — *Seacon* Source Level as a Function of Frequency and Thrust

Frequency	Source Level (dB re 1 μPa/m - Hz)			
	10% Thrust (1.40 knots, or 2.60 km/h; max range of 1.4 km)	40% Thrust (3.22 knots, or 5.95 km/h; max range of 2.8 km)	70% Thrust (4.64 knots, or 8.59 km/h; max range of 4.0 km)	100% Thrust (5.62 knots, or 10.40 km/h; max range of 4.0 km)
50	152.8 ± 3.2	151.4 ± 2.4	160.1 ± 1.8*	163.4 ± 1.7*
100	149.8 ± 2.7†	147.8 ± 1.7	149.7 ± 1.7	152.7 ± 1.2
200	143.6 ± 1.6*	140.6 ± 3.3†	142.6 ± 2.9	144.7 ± 1.7
300	142.9 ± 3.4*	143.6 ± 3.4*	136.4 ± 2.4	138.8 ± 2.2
400	133.8 ± 3.9	135.1 ± 4.4	136.4 ± 3.5	136.9 ± 3.2
500	131.6 ± 3.3	133.6 ± 2.5	133.2 ± 2.5	132.2 ± 2.2

*Strongly affected by a spectral line.
†Weakly affected by a spectral line.

ESTIMATED SOURCE-LEVEL SPECTRA

To analyze the data further, we had to reconstruct the source-level spectra of the *Seacon* at different thrust levels. Figures 5a and 5b show the estimated source-level spectra of the *Seacon* for four ranges at 10 and 100% thrust. We obtained these spectra by scaling the measured received levels so that they passed through the calculated source levels at each range and frequency. We used linear interpolation between frequencies. This process removes the gross physical distortion of the spectrum due to the changes in transmission loss with frequency. Some error due to transmission-loss fluctuations must be expected, but the process seems to have worked quite well, as is indicated by the high degree of internal consistency in Fig. 5b. A lot of the variability in Fig. 5a must be attributed to actual variations in the data. For example, the lines at the lower frequencies are regular and consistent. This systematic variability is reflected in the standard deviations in Table 1.

The most striking feature of these curves is the strong line structure at 10% thrust and the reduced line structure at 100% thrust. The lines at the harmonics of about 33 Hz are due to the

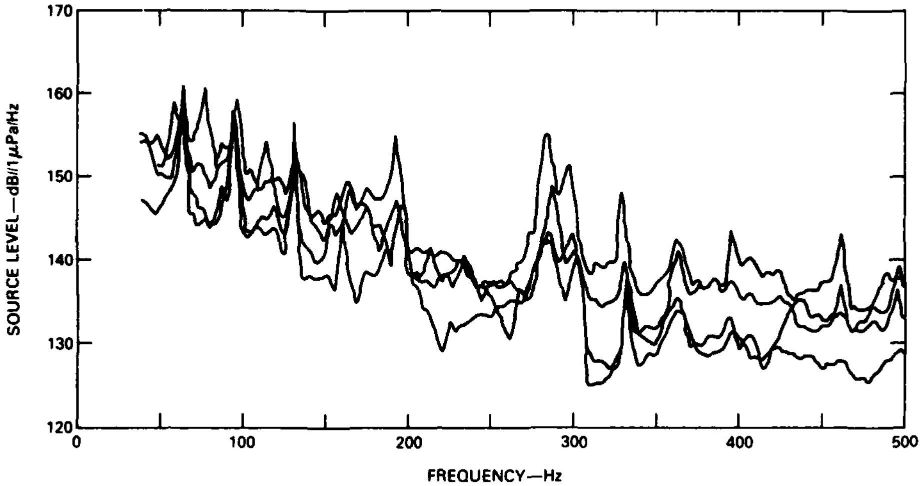


Fig. 5a — Four sample spectra at 10% thrust, showing the variability of the levels except for the stable line components below 150 Hz

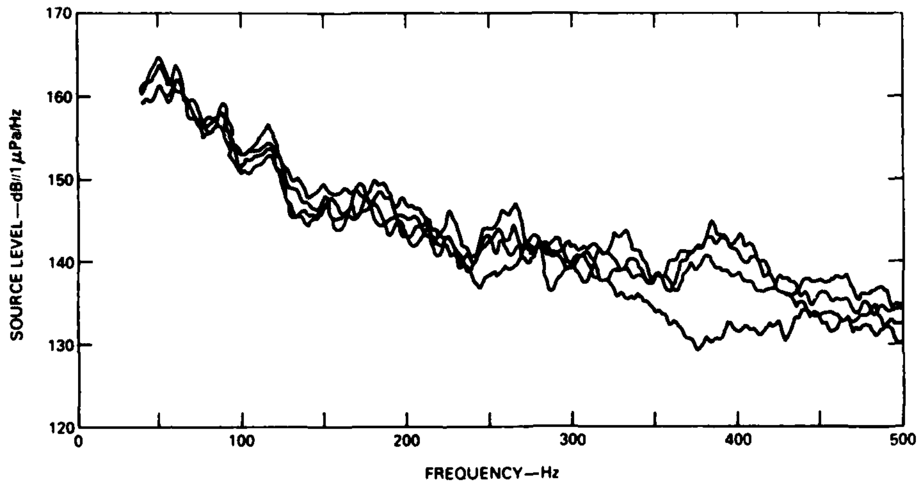


Fig. 5b — Four sample spectra at 100% thrust, showing little variability in level

engine speed of approximately 2000 rpm in a light-load condition. These lines vary slightly with range, as is to be expected due to changing load conditions on the engine. Further, at 100% thrust the lines have shifted down in frequency to harmonics corresponding to the loaded engine rating of 1800 rpm. These lines at 100% thrust are not as readily apparent due to an increased broadband cavitation-noise background level, but at the lower harmonics they seem to have approximately the same level as at 10% thrust. The higher harmonics seem to have fallen in level at the higher thrust level, particularily those between 280 and 300 Hz.

The secondmost interesting facet is the increase in background level at the lower frequencies and its degree of regularity. We attribute this source of noise to propeller cavitation.

Interestingly, the spectra at 10% and 40% thrust levels are nearly identical, and the broadband component can be described as -6 dB per octave relative to a source level at 1 Hz of 186 dB re 1 μPa/Hz. This observation is in accord with measurements made by Grey above 1 kHz [5]. At the higher thrust levels, 70% and 100%, these slopes seem to change to -7 dB and -9 dB respectively. The increased regularity of the 100% thrust spectra is attributed to a more nearly constant load condition. The automatic pilot was constantly adjusting the thrust directions and levels to maintain a straight course, and at the lower thrust levels this would amount to a larger fraction of the noise radiated.

Also of interest is the strong line at about 285 Hz, which was visible at all thrust levels except 100%. The frequency of this line did shift with the changing thrust level but is not harmonically related to the other lines. This line is probably engine related, since the *Seacon* uses three independent diesel engines. Thus this line could be the 8th or 9th harmonic of an engine. It also could be related to the gears between the engines and the propellers.

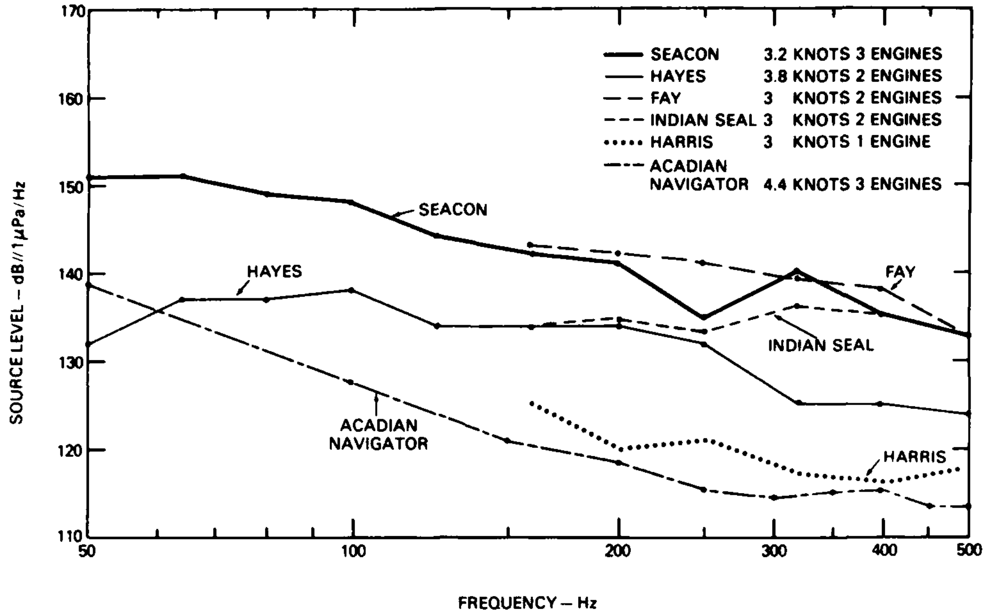
Blade-rate lines at harmonics of four times the propeller revolutions per minute (4×140 rpm = 9.3 Hz) are not observable in this frequency range. There is some possible indication of the first few harmonics below 30 Hz, but this frequency region is heavily affected by tape noise as well as being below our range of interest.

COMPARISON OF NOISE LEVELS OF THE *SEACON* AND OTHER VESSELS

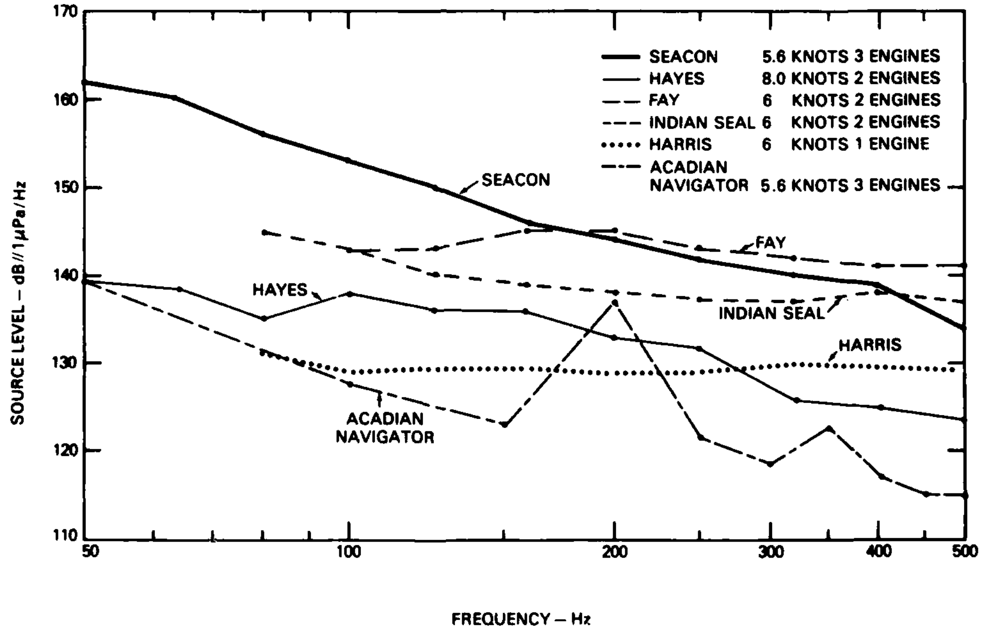
Figure 6 compares the third-octave noise from the *Seacon* at two speeds with other array-handling vessels which have been used by the Navy. The USNS *Hayes*, which is the principal vessel of NRL, is a large catamaran with variable-pitch propellers. The R/V *Danial L. Harris* III, originally a World War II patrol craft, is now the towship of the Naval Underwater Systems Center, Central Test and Evaluation Activity, used for array evaluation. The *Harris* is equipped with a special hydraulic slow-speed propulsion unit. The M/V *Indian Seal* and the M/V *H.J.W. Fay* are both offshore supply vessels or mudboats. The data in Fig. 6 for these last three vessels are taken from Ref. 6.

Figure 6 also includes measurements of the M/V *Acadian Navigator*, an offshore supply vessel [7]. This vessel has several features designed to minimize noise radiated from the ship. The principal feature is a diesel-electric propulsion system with the diesel generators mounted on isolation mounts on the main deck near the bow. The curves in this case represent the upper limit of the broadband noise only. There are, in addition, numerous spectral components about 5 dB higher at multiples of the diesel generator frequency, 30 Hz, and a particularily strong line, 135 dB, at 360 Hz. The peak at 200 Hz in Fig. 6b is attributed to cavitation noise.

As can be seen from these figures, the *Seacon* is comparable to the two mudboats above 200 Hz but is significantly louder than the *Harris*, the *Hayes* and the *Acadian Navigator*. The variable-pitch propellers on the *Hayes* and the special propulsion systems on the *Harris* and the *Acadian Navigator* significantly reduced their levels. Below 100 Hz the noise level of the *Seacon* continues to rise substantially, whereas the levels of the other vessels tend to flatten out. This difference in spectra must be attributed to the cycloidal propellers. Most regular propellers create a broadband cavitation spectrum with a broad peak in the neighborhood of 75 to 200 Hz for ships of this size. The spectrum of the *Seacon* is continuing to rise below 75 Hz. Thus the *Seacon* tends to radiate considerably more noise energy than the other vessels, but this extra noise is to be found principally at frequencies below 100 Hz. No explanation of this spectrum has been proposed in the literature, probably because few vessels use Voith-Schneider propellers and because the leading blades affect the flow pattern on the trailing blades, making computations nearly impossible. The broadband noise of the *Seacon* probably peaks at some relatively low frequency at or below 50 Hz.



(a) At speeds of 3 to 3.8 knots



(b) At speeds of 5.6 to 8.0 knots

Fig. 6 — Third-octave comparison of the *Seacon* to five other array-tow vessels used by the Navy

CONCLUSIONS

The *Seacon*'s noise level, in terms of the *Seacon*'s source-level spectra measured at four thrust levels, is equivalent to the noise level of other towships above 150 Hz when special quieting efforts have not been made. The *Seacon*'s spectra, at the lower thrust levels, were composed of strong harmonics of the engine rpms and broadband cavitation noise. At the higher thrust levels, the spectra were dominated by cavitation noise. This suggests that noisewise, the *Seacon* would be acceptable for deployment as a development-tchnology platform for systems designed for frequencies above 150 Hz. Due to its unique propulsion system the *Seacon* has station-keeping and slow-speed-positioning capabilities matched only by similarily equipped vessels. Since its noise level at the higher frequencies is comparable to that of other vessels involved in acoustic work, it should be considered the vessel of choice for development efforts that require deploying large equipment overboard.

Not surprisingly, the levels of the three vessels for which no special quieting efforts had been made where significantly louder, 10 to 20 dB, than those for which special efforts had been made. Variable-pitch propellers are a recognized means of reducing cavitation noise, and the noise levels shown in Fig. 6 are an excellent example of this effect. Two propulsion systems, the hydraulic slow-speed system on the *Harris* and the diesel-electric system on the *Acadian Navigator*, were both highly effective in reducing the radiated noise, but at higher speeds the *Acadian Navigator* was quieter. Thus this study and the studies listed in the references indicate that the features included in the design of the *Acadian Navigator* are preferred for array-towing applications and that features included in the design of the *Seacon* favor it for station-keeping and slow-speed-positioning operations.

ACKNOWLEDGMENTS

We acknowledge the cooperation of Captain Peck and the crew of the *Seacon*. George Spencer, Charles McLaughlin, and Larry Mendlow at the Washington Navy Yard were helpful in arranging for the measurements and in supporting the analysis. Ray Boswell of the Naval Intelligence Support Center provided necessary calibration data on the sonobuoys. Ron Dicus of NRL helped with the transmission-loss calculations, and Rolf Anderson of NRL helped with the equipment and in locating noise spectra for the *Hayes*. Finally, we are particulary grateful to Jack Bright of NRL, who was the project engineer for these measurements.

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